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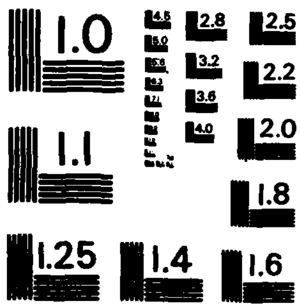

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Automatic scaling of Digisonde ionograms by ~~ULCAR's~~ the ARTIST system is discussed and reference is made to the ARTIST's success in scaling over 8000 ionograms. Some of the numerical methods implemented by the ARTIST system are described in detail and the logic of the ARTIST software is explained. The input necessary to and the output of the ARTIST system are also discussed.

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1.0 INTRODUCTION

Any real time system that requires information about the ionosphere simply cannot depend on manual scaling because of both speed and reliability. For such systems automatic scaling of ionograms is a necessity. To be successful an automatic scaling algorithm must be capable of correctly scaling both "easy" ionograms recorded during quiet conditions with relatively low interference level, and "difficult" ionograms recorded during ionospheric disturbances or high interference level. After nearly five years of development the ULCAR ARTIST system can perform the above task reliably and in real time automatically reducing ionograms into several useful forms.

The ARTIST comprises hardware and software components and is a part of the ULCAR Digisonde 256 system. The ardware is contained in a 10.5-inch high rack mounted chassis and consists of a microcomputer with an 8086 microprocessor and an 8087 math coprocessor, 512K of RAM, and two disc drives. The software consists of a CP/M operating system with a Microsoft Fortran compiler and the ARTIST software. Upon receiving a raw ionogram, ARTIST software immediately begins to process the data to produce the virtual height trace for the ionogram, h'(f), the usual ionospheric scaling parameters, plus ampliude, spread F and Doppler information. From the autoscaling information the electron density profile can be generated by the profile-fitting method (Reinisch and Huang, 1983). This method is ideally suited for autoscaled results as discussed in Reference 1. The results of ARTIST are outputted to a standard RS232C port for connection to a local terminal or remote computer at a central site. All of the above tasks are performed in real time before the next ionogram is ready for processing.

Autoscaling routines have been developed by other institutions in the past but they work only for the specific types of ionograms they were tailored to, perhaps as a result of testing only on a few ionograms. To demonstrate the versatility and accuracy of ARTIST, the autoscaling routine has been tested on some 8000 ionograms from Goose Bay, Labrador, for the months January, April, July, and September of 1980. This data base is representative of one year's data covering all seasons and all types of ionospheric conditions. For the same period the autoscaling results were compared with manually scaled hourly ionograms (approximately 2200). The comparison of the autoscaled data to the manual data was the topic of a test and evaluation report[2] from which the quality of the autoscaled results is apparent. For example, Air Force Global Weather Central requirement for high-latitude stations for foF2 is foF2 ± 1 MHz in 80% of the time; the autoscaling meets this criterion in 96% of roughly 2200 ionograms. Comparison of the ARTIST h'(f) traces with the manually scaled h'(f) traces for corresponding ionograms shows very good agreement.

The ARTIST system outputs the following information for each ionogram; virtual height trace h'(f), and the following parameters: foF2, foF1, fminF, MUF(3000)F, M(3000)F, range spread F, frequency spread F, h'F, h'F2, foE, foEs, fminE, range spread E, frequency spread E, h'E, h'Es. The maximum usable frequency (MUF) for other than 3000 km distances can easily be determined. Also average echo amplitude values are given for each megahertz, normalized to a 100 km reflection height; the motion of the ionosphere is analyzed using the Doppler transition frequencies. The results for one ionogram represents one data file identified by station code, coordinates, date, time and sounder operation parameters. The program is constructed to facilitate the addition of ULCAR's electron density profile program.

In the following sections the ARTIST software is described and the mathematical procedures implemented by ARTIST are discussed.

2.0 FUNCTIONAL DESCRIPTION

2.1 Overlay (BISA, 0, 0) Program ARTIST - The Driver Program for the ARTIST Algorithm

2.1.1 Subroutine SUMENG

SUMENG sums the amplitudes of a trace segment according to tagging (O or X echo). Input is the starting and last frequency in the segment and the type of echoes to sum, O or X. The output is the number of points in the sum and the sum of the specific amplitudes on the curve.

2.1.2 Subroutine INIT

INIT initializes one or two dimensional arrays to zero. Input is the array to be initialized and its dimensions, output is the null array.

2.1.3 Subroutine UNPAK

UNPAK extracts the amplitude and status information as a function of frequency. Two records of data are unpacked at a time where each record contains ten frequency lines and each frequency line contains 128 amplitudes and status tags corresponding to virtual heights. In each operation the TT and K values of the preface are tested to insure vertical ionogram data. The predicted foE is calculated and other necessary information, such as day, hour, minute, etc., is extracted from the preface.

2.1.4 Subroutine TSTTK

TSTTK checks that the TT and K preface values of the first two records of the ionogram correspond to vertical ionogram data.

2.1.5 Subroutine SPREF

SPREF unpacks the preface and stores it in the array IPREF. Odd number records have the preface stored in the first 24 elements, even number records use positions 1 through 16 and 25 to 32.

2.1.6 Subroutine SDATA

SDATA unpacks the data of one frequency line into 128 amplitudes and status tags corresponding to the 128 possible digitized virtual heights.

2.1.7 Subroutine STAT1

STAT1 unpacks the status of data taken before June 14, 1980 and stores the information in the array ISTS.

2.1.8 Subroutine STAT2

STAT2 unpacks the status of data taken after June 13, 1980 and stores the information in array ISTS.

2.1.9 Subroutine NOIS (Figure 1)

The noise threshold for each frequency is determined and all amplitudes below the threshold are set to zero. Each frequency line is divided into two regions, an upper and lower 64 range bins and the noise threshold is found separately. The noise threshold is determined by distributing the 32 possible digitized amplitudes into 16 levels and counting the occurrence of each level in the region. This gives a distribution curve of occurrence vs level. The noise level is defined as the first level above the most probable level having at least half the number of occurrences as the most probable level. The lower noise level of the two regions is selected

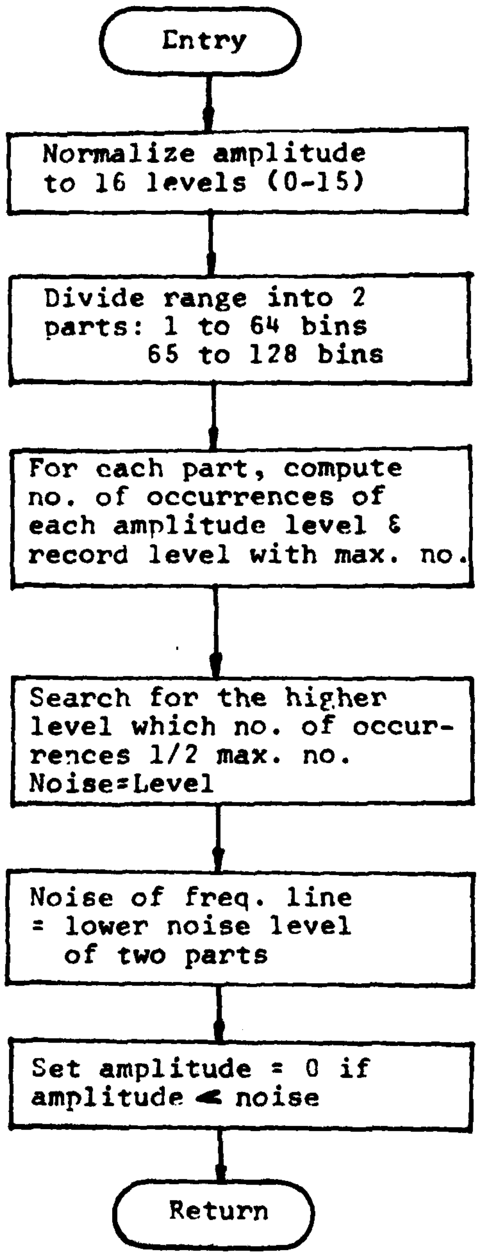

Figure 1. Subroutine NOIS Flow Chart

as the noise threshold. This level overwrites the amplitude of the first range bin for future reference.

2.1.10 Subroutine PRNLN

PRNLN prints out the data one frequency at a time, either the amplitude (ID = 1) or the polarization status (ID = 2), O, X, or B (oblique) may be printed. This routine is mainly for diagnostic use.

2.1.11 Subroutine FLM (Figure 2)

FLM marks the leading edge of a pulse. For each frequency, the position of the first maximum amplitude of an O-echo between two zero amplitudes is defined as a first local maximum (FLM). There can be unlimited FLM's in one frequency and each is flagged by a negative sign. Isolated O-pixels are ignored.

2.1.12 Subroutine CHKEC2

This routine eliminates the double echoes of E or F traces. For each frequency the double echo FLM is located and a window (five bins high for E and nine bins high for F) is placed over the FLM. The corresponding first order echo height is evaluated and a similar window is placed on it. The amplitudes in each window are summed and compared. If the sum from the double echo window is the smaller, all FLM's in it are deleted (the data is reset to a positive value). The comparison is only made when the first order echo window has at least one O-echo.

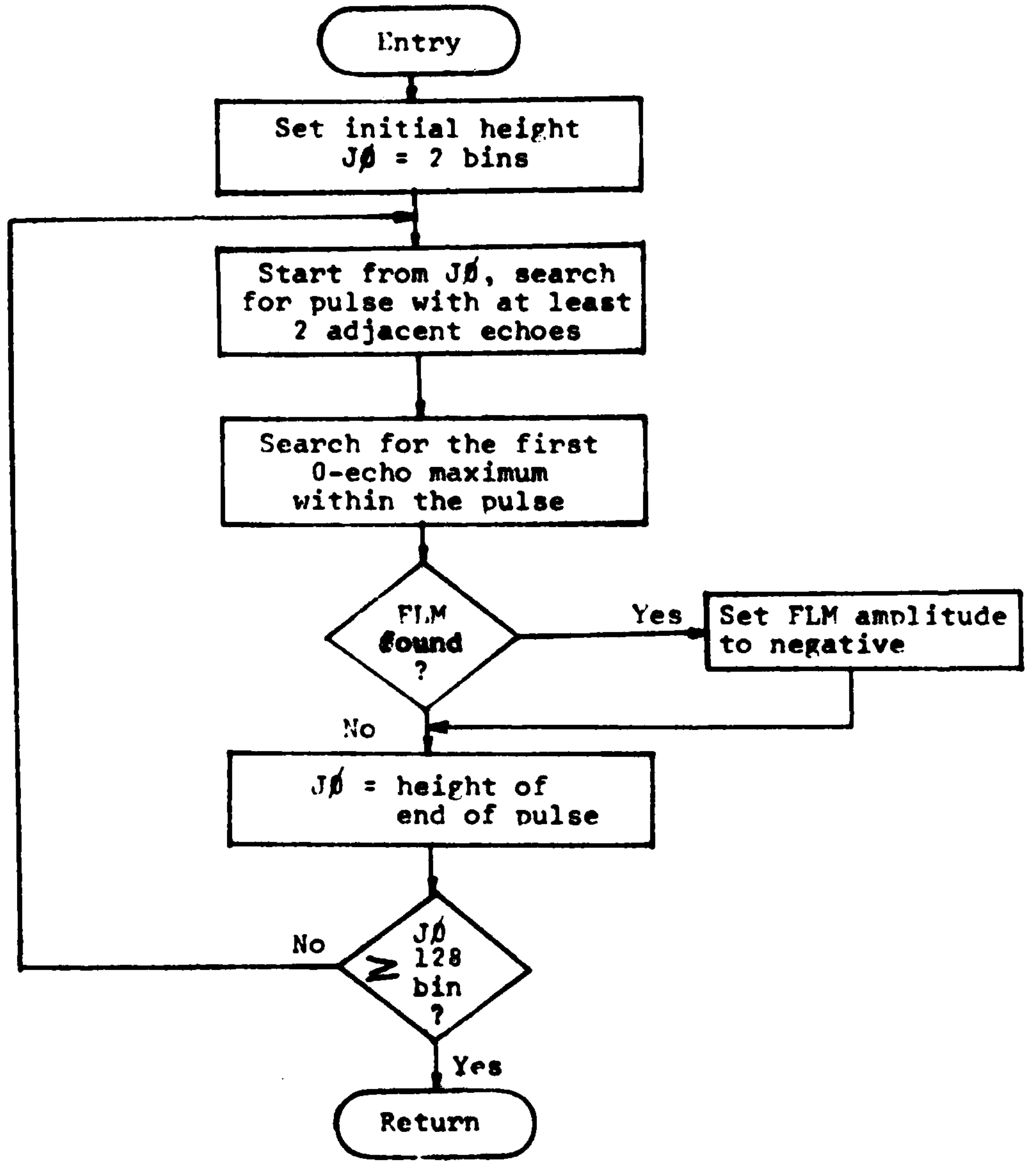

Figure 2. Subroutine FLM Flow Chart

2.1.13 Subroutine SUMAMP

The amplitudes within a specific range of a particular frequency given as input are summed and the result is returned to the calling program.

2.1.14 Subroutine TCENTR (Figure 3)

This routine locates the center of the F-trace where the echoes with significant amplitude are mostly clustered, usually in the flat portion of the trace. This is accomplished by grouping three abutting ranges together and summing the FLM amplitudes over the first 100 frequencies. The heights of the three highest amplitude sums are recorded. A five frequency by three range bin window is then moved along the frequency axis at the three selected heights in search of the maximum FLM amplitude sum. The three resulting 3 × 5 windows are inspected and the one having the greatest O-echo amplitude sum is the main trace center.

2.1.15 Subroutine SWAP

The input consists of four variables, IA, IB, IC, ID, the routine swaps the values of the first two with each other and the last two with each other (i.e. IA → IB, IB → IA, IC → ID, ID → IC).

2.1.16 Subroutine PLOTRC

This routine allows the plotting of ionograms on a line printer. Several modes are available: raw ionograms with noise suppressed, ionograms with one of the following; FLM's, baseline, trace with amplitude, trace with tagging, or trace with Doppler level.

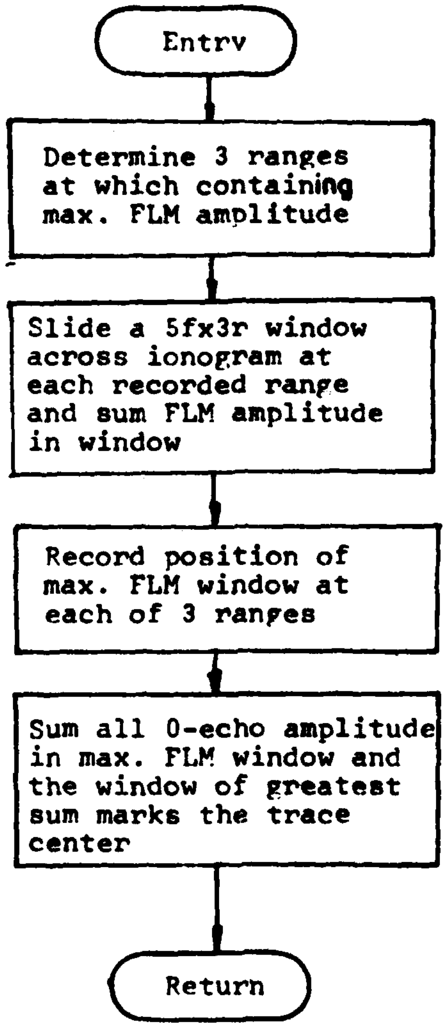

Figure 3. Subroutine TCENTR Flow Chart

2.1.17 Subroutine FILLZ

FILLZ is called with three variables I1, I2, IT. The routine sets the array ITRCF(I, IT) equal to zero from position I1 to I2.

2.1.18 Subroutine PFOE

PFOE evaluates the predicted foE value for Goose Bay, Labrador, for the year 1980 using a table in terms of day of the year, hour and minute of the day.

2.1.19 Subroutine SRANGE (Figure 4)

The average range spread of the trace, excluding the last five frequencies, is calculated. At each frequency a four range bin window is placed over the identified trace point and the amplitude in the window summed. The window is moved up the height axis in one bin steps and the amplitude recorded at each step. The amplitude at each step is compared to the trace point amplitude until a 12 dB drop is observed. The range spread is given by the height difference of the window base position from the trace point range. The average spread is calculated by the following formula

$$\mathrm{SPRED} = \frac{\sum_{f=\mathrm{minF}}^{\mathrm{topF}} \Delta h'(f)}{\mathrm{topF}-\mathrm{minF}+1}$$

where topF = critical frequency - four frequency bins. It is assumed that the height increments in the ionogram are 5 km, and the frequency increments 0.1 MHz.

2.1.20 Subroutine SFREQ (Figure 5)

The routine evaluates the frequency spread of the ionogram defined as the difference between fxI and fxF2. To

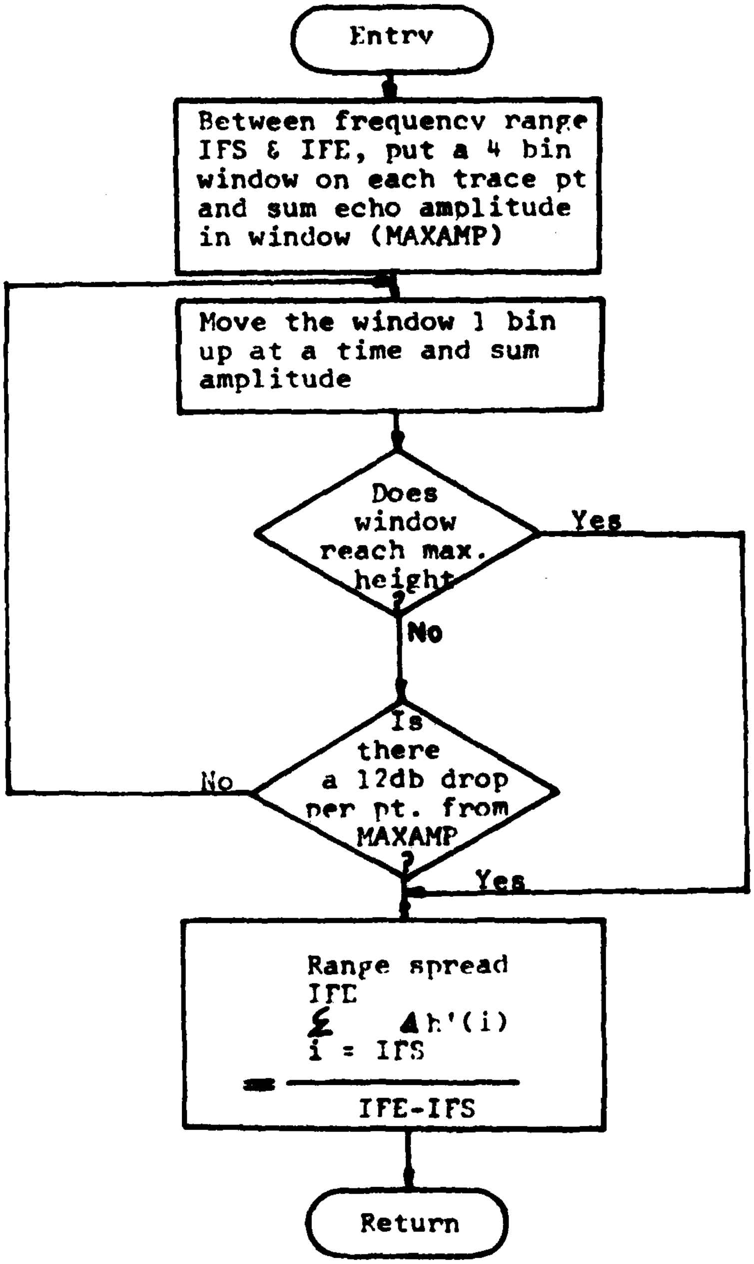

Figure 4. Subroutine SRANGE Flow Chart

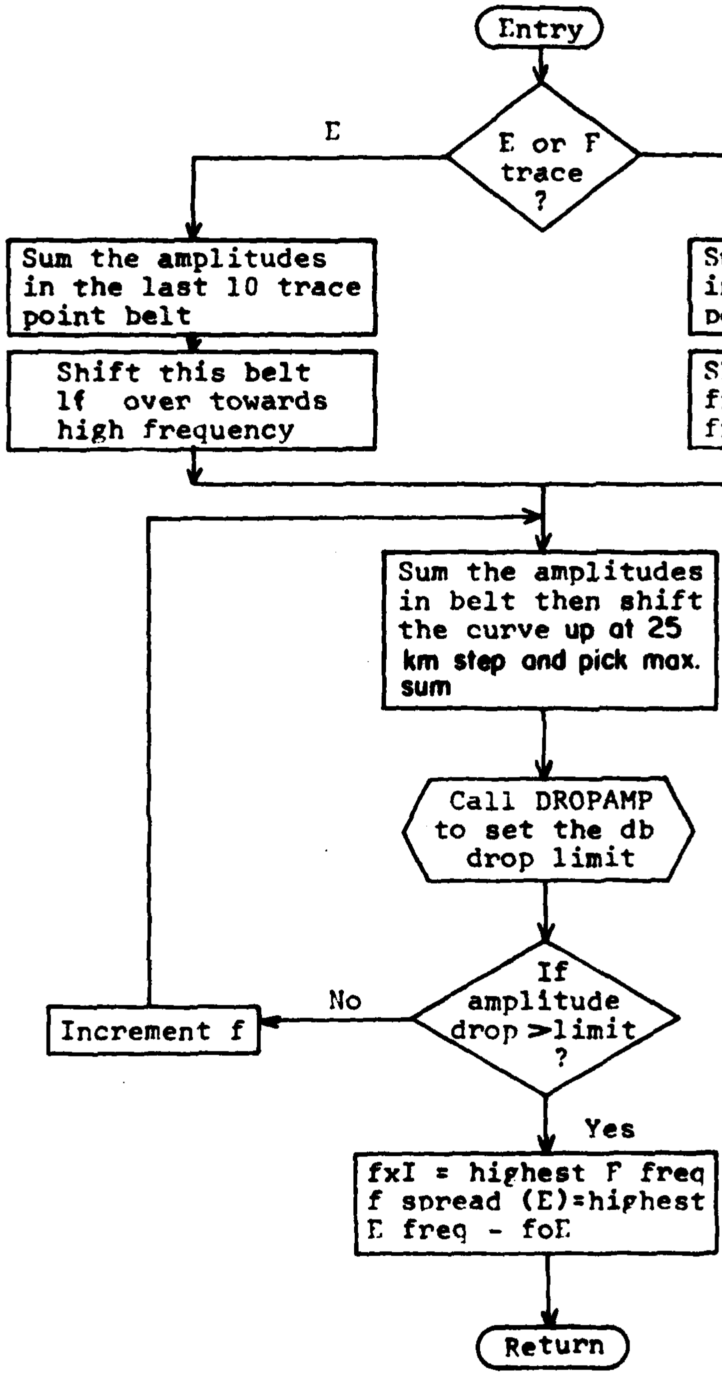

Figure 5. Subroutine SFREQ Flow Chart

evaluate fxI we start at fxF2, use the X-hyperbola as the range frame and sum the amplitude of all echoes in the frame. The hyperbola is also shifted up in 25 km steps to locate the maximum amplitude sum. The maximum sum is compared to the O-hyperbola's sum to check for a 6 dB drop per pixel. (For severe spread conditions where the baseline average range spread is more than 50 km, a 12 dB drop is used.) If the amplitude criteria is fulfilled we designate the cusp frequency fxI. If the criteria is not met we increase the cusp frequency of the search hyperbola by one step and repeat the procedure until the amplitude criteria is fulfilled.

2.1.21 Subroutine DROPAMP

This routine is called by the SFREQ and FDOWN routine, it calculates the magnitude of the trace amplitude and sets the limit of the dB drop to be used by the routines.

2.1.22 Subroutine OUTERR

For some ionograms we cannot determine foF2 due to bad data or absorption. The routine OUTERR finds these cases and outputs 999 for the foF2 frequency and the h'(f) height of the ionogram to indicate no reasonable trace could be found.

2.1.23 Subroutine SORT

This routine sorts an input array in ascending order.

2.2 Overlay (BISA, 2, 0) - The F-Region Overlay Program

F-Region

This is the driver program for constructing the F-region trace and extracting F-region parameters.

2.2.1 Subroutine BASE (Figure 6)

This routine constructs a baseline which outlines the trace by following its leading edge. The coarse baseline end (ITEND) is determined as the highest frequency with FLM's on five successive frequencies. The baseline is then generated starting at the trace center where a 5 f by 35 bin window is placed and the median range of all center window FLM's is determined. The range difference between the highest and lowest FLM is also recorded. These two values are used to set the window size for searching for FLM's for the next frequency (the range of the preceding frequency is used if no FLM is found). This process continues toward higher frequencies until no FLM's are found for five consecutive frequencies after ITEND, where it is assumed the end of the trace is encountered and the baseline point is set equal to the highest bin. Starting again at the center, the process is repeated toward the lower frequencies until the predicted foE is reached or no FLM is found on the next five frequencies.

2.2.2 Subroutine MED

This routine is called by BASE to find the median range of the FLM's in the search window. This is done using a simple sort routine.

2.2.3 Subroutine DFOF2 (Figure 7)

It determines the critical frequency by hyperbolic fitting. Two parallel curves denoting O-trace and X-trace

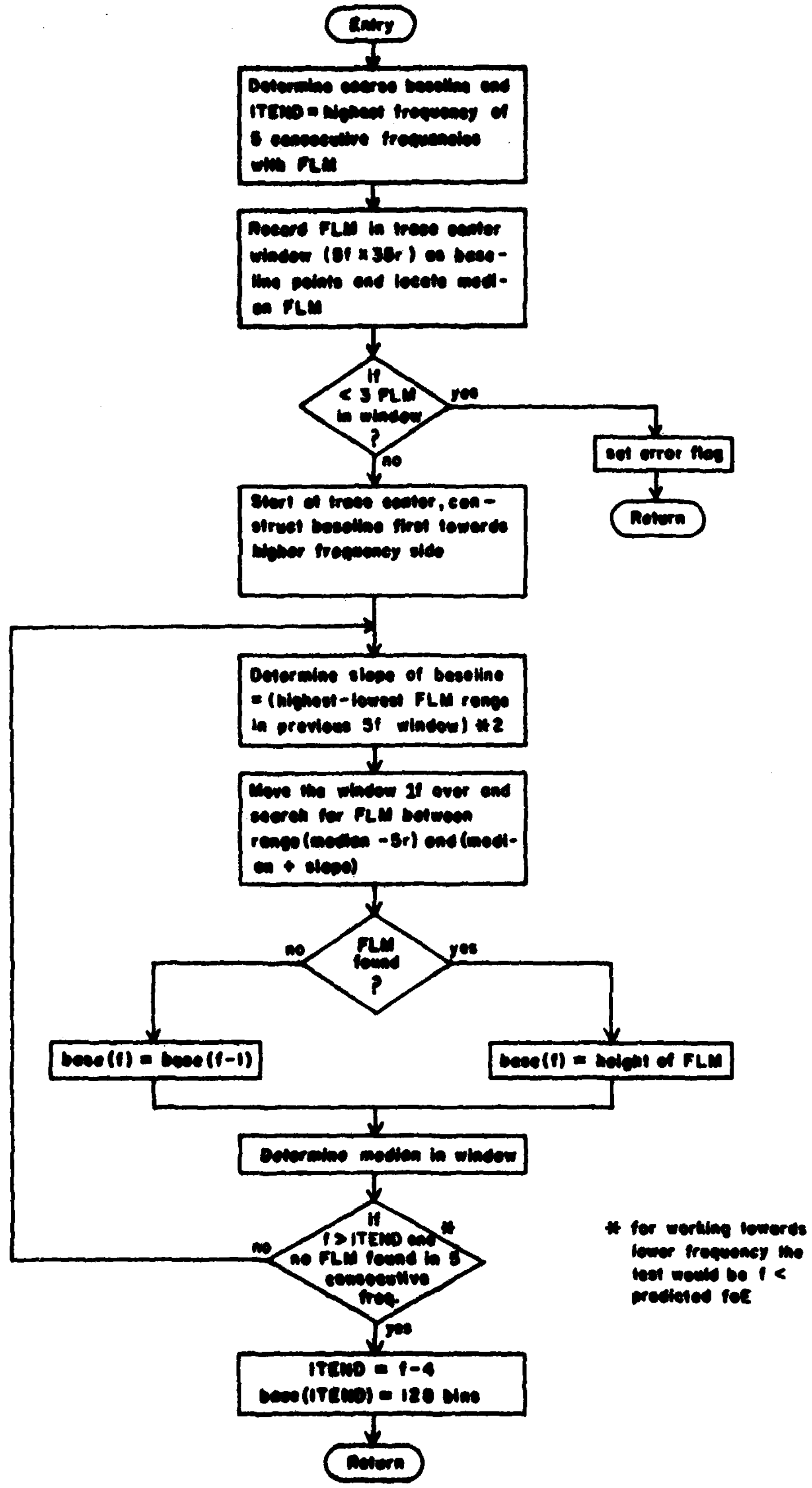

Figure 6. Subroutine BASE Flow Chart

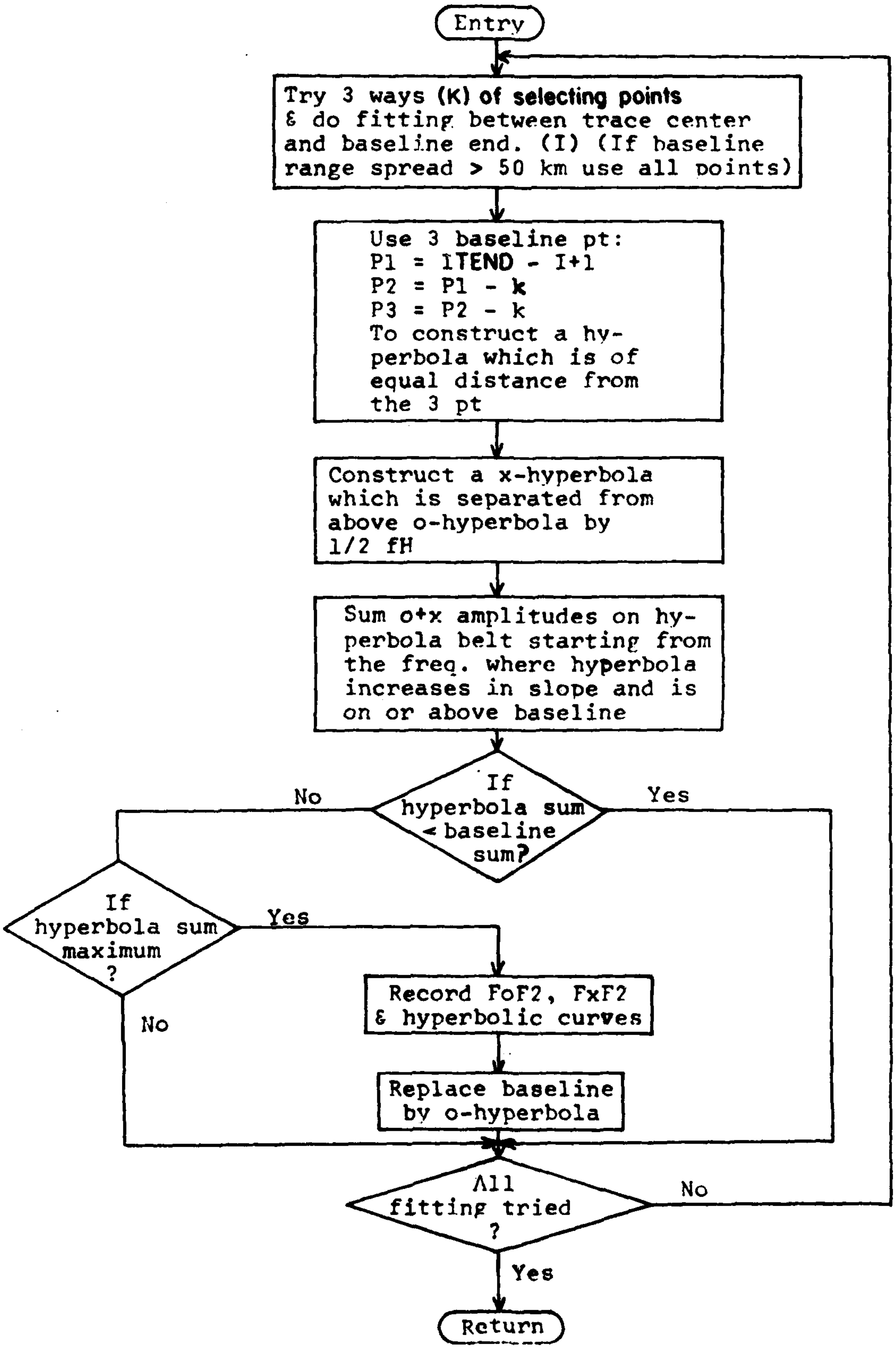

Figure 7. Subroutine DFOF2 Flow Chart

are constructed with the frequency difference equal to 1/2 the gyrofrequency. The O-hyperbola is formed by three points on the smoothened baseline. The selection of the points is described in section 5.0. The best fitted traces are those which give the maximum summation of amplitude in the curve belts. To avoid selection of an incorrect trace the following condition is employed. The maximum sum must be greater than the corresponding amplitude sum for the baseline between the same starting frequency and the baseline end.

2.2.4 Subroutine SUMBS

This routine is called by DFOF2 with a specified frequency range and it performs the amplitude summation of the baseline within the given frequency interval.

2.2.5 Subroutine SUMHYP

This routine is very similar to SUMBS except that it evaluates the amplitude summation of either the O or X hyperbola within the given frequency interval.

2.2.6 Subroutine FDOWN

Subroutine FDOWN lowers the extracted F-trace to follow the leading edge of the pulse. The amplitudes of the identified trace are summed according to the window sizes defined by each two adjacent frequencies (the window range is determined by the trace point height and the trace point height of the preceding frequency). The trace is lowered in 1 bin steps and an amplitude summation is done at each step and compared to the starting (maximum) sum. This is repeated until a 6 dB per point drop in amplitude is found or until the 15 km maximum drop is reached. The trace is now set at the new value and the size of the drop (i.e. number of bins) recorded.

2.2.7 Subroutine SMOOTH

This routine smooths the coarse baseline by fitting straight lines to segments of the baseline. Starting at the trace center, three trace points are used to construct a straight line that is equidistant from the starting three points. This line gives us the starting three smooth points. Using these three points and three adjacent baseline points we construct all straight lines using combinations of any three of our six points seeking the line with greatest amplitude. This line is used to adjust the height of the first of the three coarse points, giving us another point for the smoothened baseline. The six frequency interval is shifted down by one frequency and again we have a frame with three smoothened and three coarse points from which we smooth the point closest to the three smoothened points. This is repeated until the beginning of the baseline is reached.

2.2.8 Subroutine OBLIQ

In this routine the maximum usable frequency (MUF (3000)) and M(3000) factor for the ionogram are calculated. The vertical ionogram trace is transformed to the oblique ionogram by multiplying each frequency with the transmission factor M(h')

$$f_{ob} = M(h') \times f_v.$$

The MUF(3000) value is obtained as the highest frequency in the oblique ionogram, and the M(3000) factor is found by dividing MUF(3000) by foF2.

2.2.9 Subroutine SMOTH2 (Figure 8)

This is similar to SMOOTH except that smoothing is done from the trace center toward increasing frequencies to the baseline end.

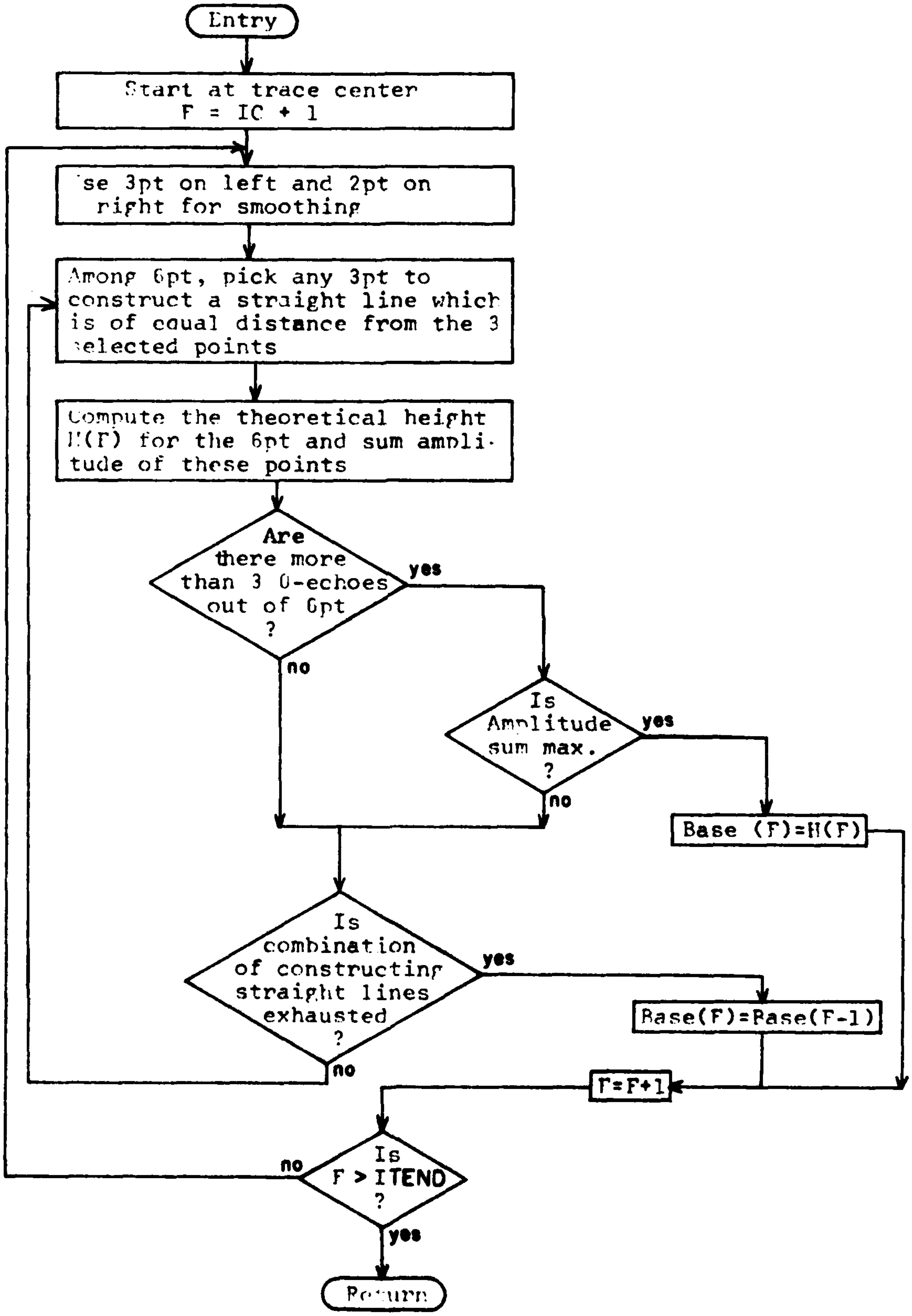

Figure 8. Subroutine SMOTH2 Flow Chart

2.2.10 Subroutine MINF

MINF determines the minimum frequency of the F-trace. Starting at the frequency where the five previous frequencies had no FLM's a 3 × 3 window is moved along the trace and the amplitude sum is performed at each step. When a window is found that has at least 40% of the amplitude of the trace center, the frequency of the first O-echo in that window is designated fminF.

2.2.11 Subroutine MINHT

Given a starting frequency of the search the minimum height of the trace (F1 or F2) can be found. For h'F the search range is between the beginning of the trace to the trace center, for h'F2 the range is from foF1 to foF2. Considering three trace points at a time, the routine selects the minimum height of the trace by applying two criteria; the average height of the three points must be a minimum and the height differences among the three points must be the minimum. The minimum height is set equal to the average of the three points meeting the above criteria.

2.2.12 Subroutine FOF1F

Given the autoscaled h'(F) trace this routine determines the presence of an F1 layer and when present the critikal frequency of the layer. The method relies on the fact that just before the critical frequency the slope approaches infinity and just after foF1 the slope is close to zero or negative. The routine searches from 1.4 foE to 2.0 foE as possible foF1 points. At each point we take the four preceding points and the next four points; using linear regression on the two sets of five data points (note the point in question appears in both data sets) we determine the slope before and after the point in question. We apply a double criteria

to the point, the slope before must be greater than 50.0 km/MHz and the slope after must be less than 20.0 km/MHz. When both criteria are met by a point simultaneously the search is stopped and the point is designated foFl and the presence of the Fl layer is recorded. If no point in the range meets the criteria we indicate no Fl layer is present.

2.2.13 Subroutine SLOPE

Subroutine SLOPE is called by the FOFlF routine. Given a particular frequency on the trace, SLOPE uses the given point and the four preceding points and the given point and the four next trace points to form two sets of five points. For each set of points the slope is evaluated using linear regression and compared to a prechosen value. Flags are set depending on the comparisons and the information is returned to FOFlF.

2.2.14 Subroutine LINREG

Given an input array of five frequencies and heights, the slope of the points is obtained by linear regression and returned to the calling program.

2.2.15 Subroutine DEPOLE

This resets all FLM's back to positive values since the FLM's are no longer used in the processing of ionograms.

2.3 Overlay (BISA, 3, 0) Program DOPAM

This is the driver routine for Doppler analysis.

2.3.1 Subroutine MEDAMP

This routine sets up a five frequency window at each MHz on the trace points for the E, Es, and F regions and finds the median amplitude of the vertical echoes occurring in the window.

2.3.2 Subroutine DOPAMP

This is called from MEDAMP or DOPTRN. It determines the median of amplitudes or Doppler levels in the defined window according to the variable JDA.

2.3.3 Subroutine CALVEL

This routine calculates the ionospheric velocities at transition points according to the formula

$$V_f = \frac{\text{Doppler frequency} \times C}{2 \times \text{Doppler transition frequency}}$$

(C = speed of light).

2.3.4 Subroutine STRAMP

Called by DOPAMP, this routine stores amplitudes of window and normalizes them to the reflection height of 100 km before sorting to find median.

2.3.5 Subroutine STRDOP

Similar to STRAMP except the Doppler levels are stored.

2.3.6 Subroutine DOPTRN (Figure 9)

This is set up for the E, Es, and F-regions. The routine finds transition points along the traces. A three

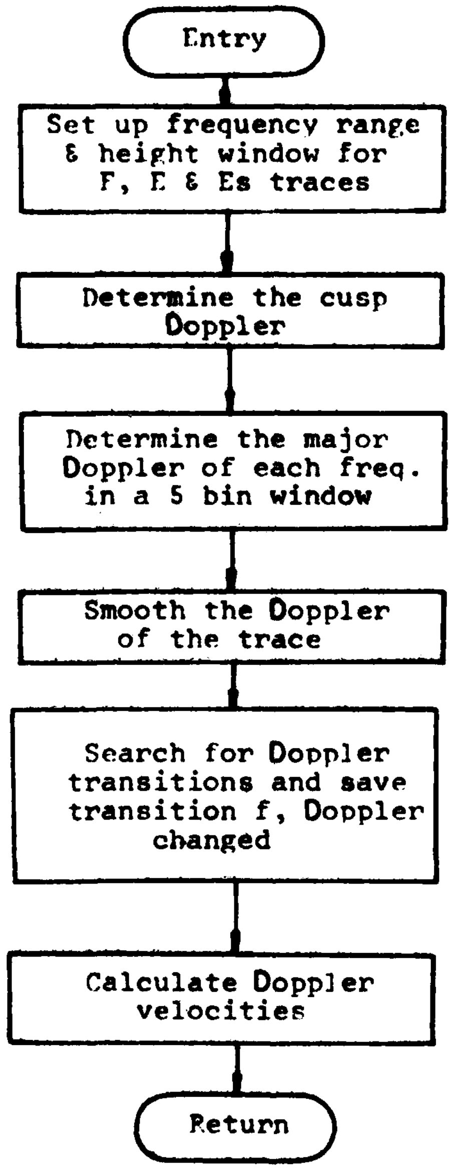

Figure 9. Subroutine DOPTRN Flow Chart

frequency window is used to smooth the recorded Doppler levels by setting the middle level equal to the end levels if one, the end levels are equal and two, the middle differs from the ends by one level, i.e. 323 becomes 333. Tests are made for transitions and if found they are recorded.

2.3.7 Subroutine TRAND

This is called by DOPTRN to test for transitions. The Doppler transition is defined as occurring when the Doppler levels are the same for five or more frequencies before and after the transition point (e.g. 111111-000000).

2.3.8 Subroutine MEDIAN

This routine sorts an array from STRAMP or STRDOP and finds the median value of the array.

2.3.9 Subroutine PCHAR

PCHAR encodes the median amplitude for each MHz for printing out.

2.4 Overlay (BISA, 1, 0) Program EREGON

This is the driver program for calculating the E-region traces (E and Es) and parameters.

2.4.1 Subroutine ETRACE (Figure 10)

This routine calculates the E-region trace and parameters describing the E-region, i.e. foE, h'E, y_E, etc. The method assumes the electron density profile is adequately given by

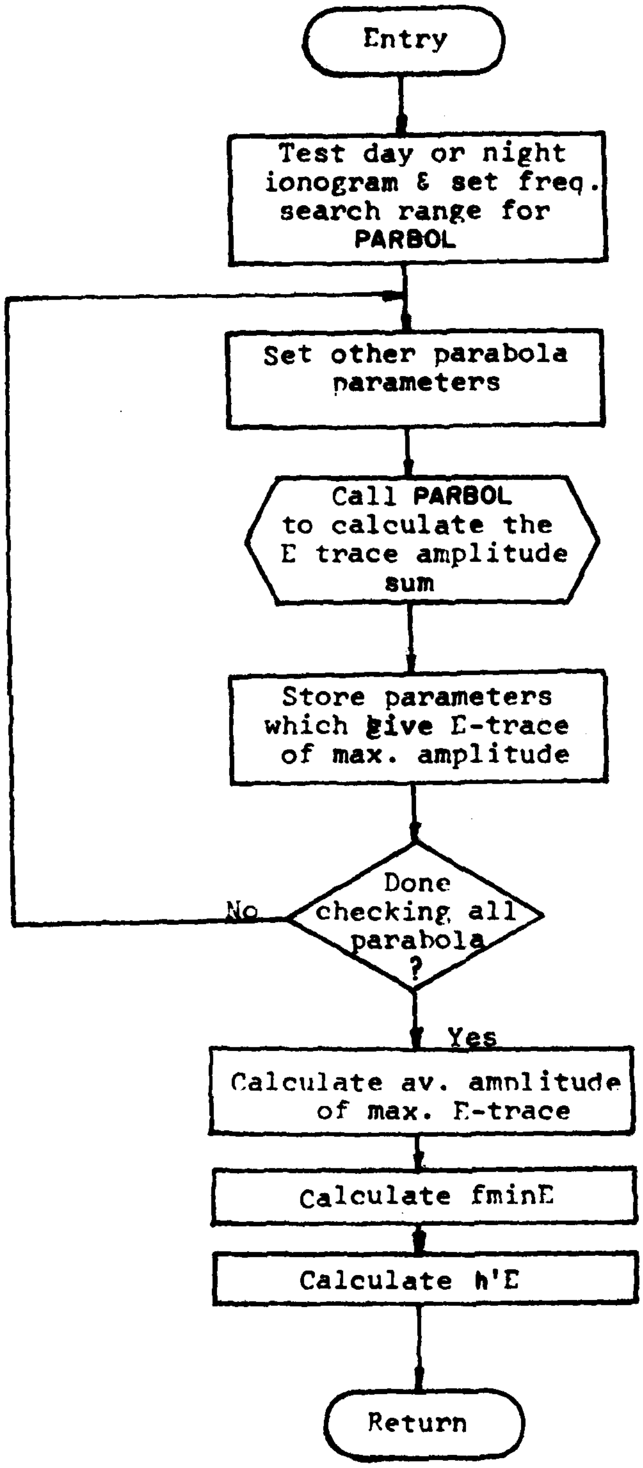

Figure 10. Subroutine ETRACE Flow Chart

$$N = N_m \{1 - (\frac{h-h_E}{y_E})^2\}.$$

From this the virtual height is given by

$$h'(f) = \int_0^{h(f)} \mu' \, dh,$$

and neglecting the effect of the geomagnetic field on the group index of refraction, μ', we can integrate giving

$$h'(f) = h_E - y_E + \frac{1}{2} y_E \frac{f}{f_E} \ln \frac{f_E+f}{f_E-f}.$$

The function $h'(f)$ is fitted to the E-region echoes by optimizing the three unknowns h_E = height of the peak of the E-layer parabola, y_E = half thickness, and f_E = foE, i.e. the critical frequency of the E-layer. These three parameters are determined such as to maximize the average signal amplitude of the ordinary vertical echoes traced out by the h'(f) function. The search range for f_E is ±.3 MHz about the predicted value when the predicted value is greater than 2.5 MHz otherwise an extended search algorithm is used. The range of h_E is from 95 to 180 km and for y_E it is from 10 to 40 km. Once the E trace is found calls are made to routines to 1. may extend foE one frequency bin, 2. lower the trace to leading edge of pulse, 3. evaluate fminE, and 4. evaluate h'E(f).

2.4.2 Subroutine PARBOL (Figure 11)

Called from ETRACE with the parabola parameters FP = f_E, IH = h_E, IY = y_E, PARBOL evaluates the amplitude of the points traced out by the corresponding h'(f) functions. For a given FP and IY it creates 17 parabolas by considering all IH in the range 95 to 180 km and selects the one with maximum amplitude. When parabolas have the same amplitudes the one chosen is

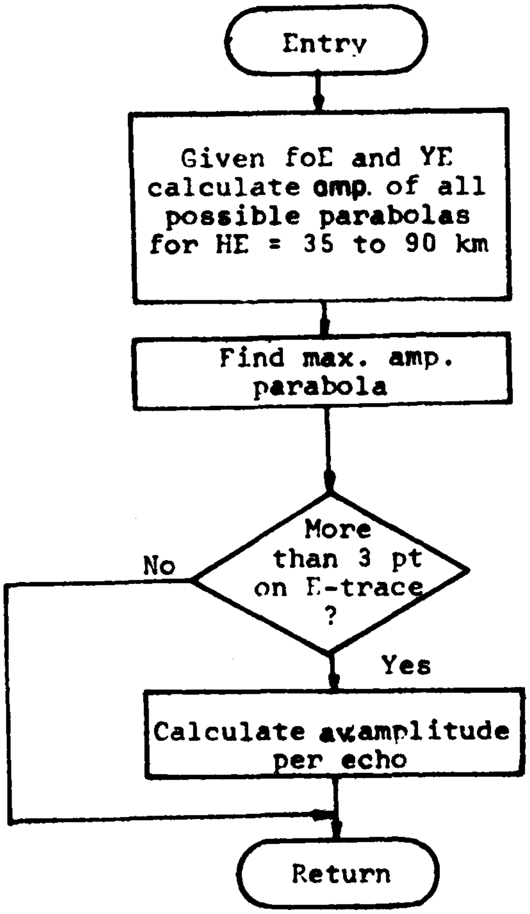

Figure 11. Subroutine PARBOL Flow Chart

1. the one with the lower FP,
2. the one with the lower IY,
3. the one with the lower IH.

This routine, also described in section 5.0, can also be called to evaluate only the amplitude of one parabola. Caution - the routine is only valid for 5 km steps in the height range as is presently done on the DGS 128PS data we have processed.

2.4.3 Subroutine XTENDE

This routine allows foE to be increased one frequency unit. The reason this is done is that the maximum amplitude trace drawn out by the ETRACE results is often short. To better compare with manual scaling we allow foE to increase one frequency unit if the following criteria is met. A five range bin window is placed (starting one bin lower than the foE trace point) at the next frequency (i.e. foE + .1 MHz) and if at least three of the five echoes are O echoes foE is increased, otherwise foE remains unchanged.

2.4.4 Subroutine ES (Figure 12)

This routine evaluates foEs if present. A 3 × 3 maximum amplitude window in the E-region is found by first summing all frequencies to 16 MHz as a function of range giving the maximum amplitude three range bins. Next the three range bins are summed from foE - 1.0 to 16.0 MHz and the maximum 3 × 3 window is obtained. The 3 × 3 window is moved outward, past foE, one frequency step at a time. At each step we sum the O-amplitudes within the window and apply a double criteria; the 3 × 3 window must have at least five O-echoes and the amplitude sum must be greater than 5 × (AVAMP-10). The factor of five is because of the five O-echo minimum and

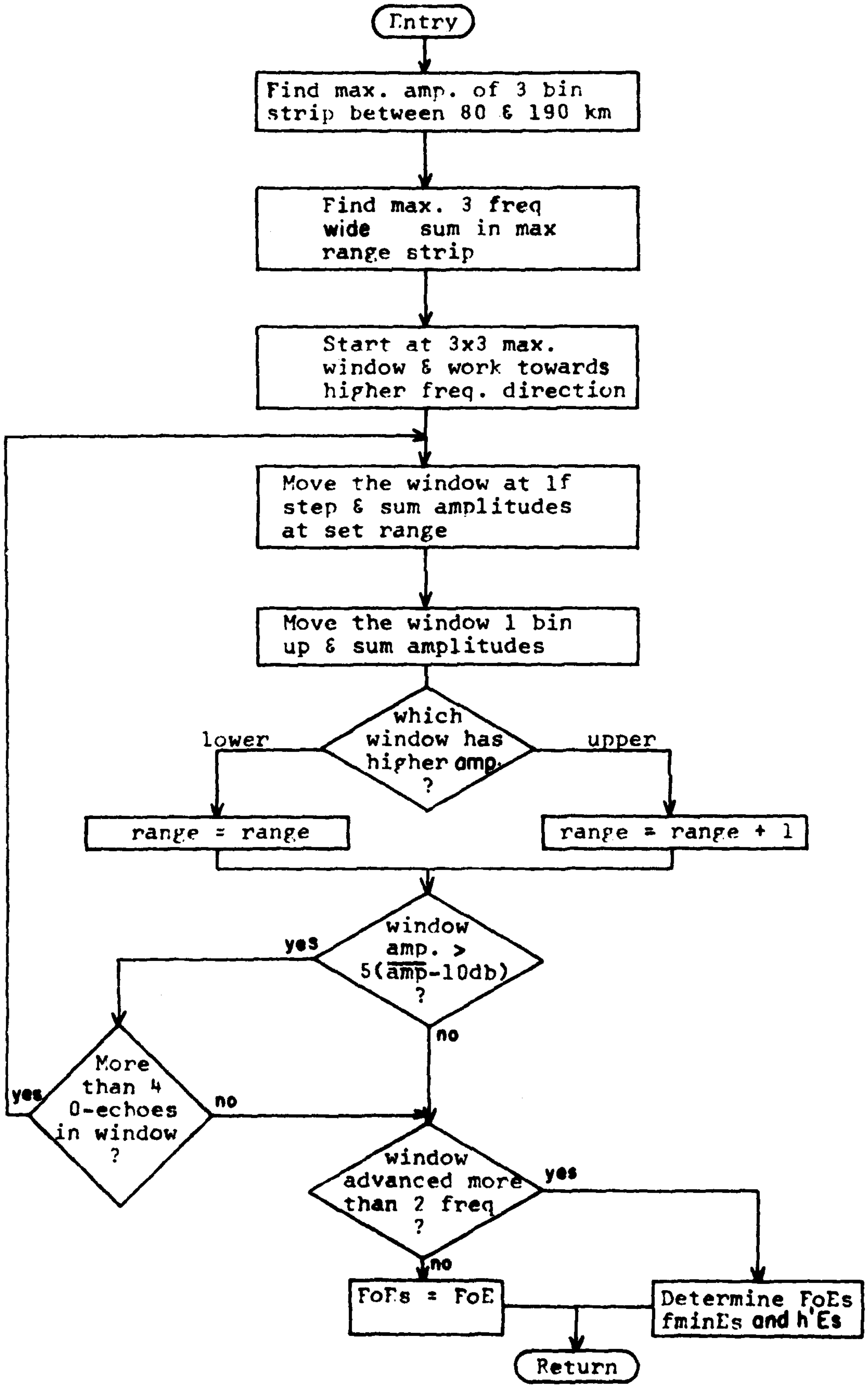

Figure 12. Subroutine ES Flow Chart

we allow a 10 dB per point drop from the average amplitude (AVAMP) of the E-trace. The following safeguards appear.

1. The resulting foEs must be greater than foE + .2 MHz otherwise foEs is set to foE.

2. The search must move at least two frequency bins before we accept any foEs value.

3. The trace (Es) is allowed to rise by considering a 3 × 3 box one bin higher at each step. If the amplitude sum of the upper box is greater than the lower, we jump up one step.

2.4.5 Subroutine EDOWN

This routine is similar to FDOWN, it lowers the E trace to follow the leading edge of the pulse. This is accomplished by lowering the parabola (decreasing h_E) and summing the amplitudes until the sum is 6 dB per point lower than the maximum amplitude trace. The lowering is stopped when the amplitude criteria is met, when a 20 km maximum lowering is met or when the lowest portion of the parabola (h_E-y_E) reaches an 80 km minimum. The new parabola parameter and the number of range bins in the drop are recorded.

2.4.6 Subroutine ECUSP (Figure 13)

This routine defines the search range for foE when the predicted foE value is less than 2.6 MHz. The method sums the range bins from 95 to 175 km as a function of frequency and find the maximum amplitude three frequency wide sum. The range is determined by searching to the right until a three frequency wide sum is less than .5 of the maximum sum and by searching to the left until a three frequency wide sum is less than .75 times the maximum sum. The search range is returned to the calling program.

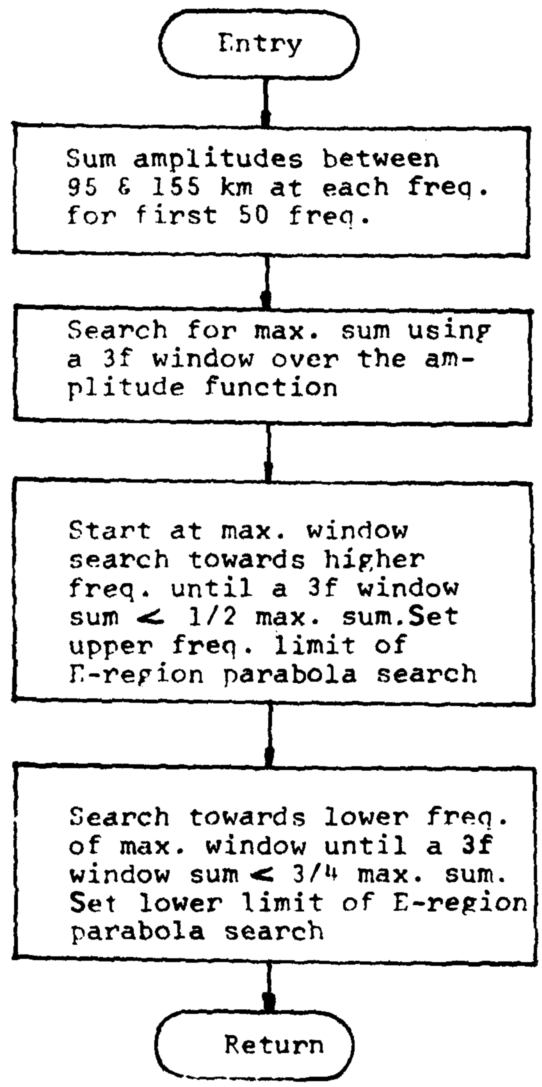

Figure 13. Subroutine ECUSP Flow Chart

2.4.7 Subroutine FEMIN

This routine calculates fminE by summing all amplitudes in the height range from 95 to 175 km as a function of frequency. Starting at the first frequency bin three frequency wide sums are made until one is obtained that is greater than 100 dB. The first frequency bin in the sum having an echo (i.e. amplitude > 100) is designated fminE.

2.4.8 Subroutine ESDOWN

This routine lowers the Es trace in the same fashion the F trace was lowered, i.e. as function of amplitude. For a very weak Es trace no lowering is performed. The 80 km lower limit used when lowering the E trace is used here also.

3.0 INPUT

3.1 Punched Card

Card No.	Variable Name	Card Col.	Format	Variable Description
1	Jun 14	N/A	Free Format	ϕ denotes input data before June 14, 1980; 1 after June 13, 1980.
2	K1, K2, K3	N/A	Free Format	End time of input tape K1 = Julian day of the year K2 = hour of the day K3 = minute.
3	NUM	N/A	Free Format	Number of ionogram to be started for processing.

3.2 Magnetic Tape or Permanent File

Name TAPE1; No. of Files 1; Density 556 BPI; No. of Tracks 7; Type Bin. Number of words in record 216.

4.0 OUTPUT

The printed output is intermediate and final results of E, Es and F-layers in that order. The intermediate values are such things as: predicted foE, iteration of trace center (IC, JC), amplitude sum at each step, no. of bins the trace is lowered, amplitude drop in 6 dB steps, baseline, last frequency of baseline, F-trace before and after hyperbolic fitting, range and frequency spread of the trace. The information above is printed out using free format and followed by a formatted print statement to list 20 preface characters and the final results of some of the parameters as follows: (MPREF(I), I = 1, 20), FMINF, FOF2, HPRMF, SPREDF, ISFF, FXI, FMUF, FM3000, SPREDE, ISEF, HPRMF2. Format: 20I2, 2F6.1, 2F6.0, I6, 3F6.4, F6.0, I6, F5.0. Finally Doppler information is printed including Doppler transition velocities and frequencies, normalized amplitude (set to 100 km) at each MHz for each trace. The processing of each ionogram can be terminated with a plot (ionogram printout) displaying evaluated E, Es and F-trace, or plotting can be suppressed and only data listed.

In addition to the output file, final results are saved on two tapes. Tape 2 contains following records for each ionogram.

1. Preface characters and parameters, (MPREF(I), I = 1, 32), FMINF, FOF1, FOF2, FXI, FMUF, FM3000, FMINE, FOE, FOES, HOM, YMM, HPRMF, HPRMF2, HPRME, HPRMES, SPREDF, SPREDE, ISFF, ISEF, IDOWNF, IDOWNE, IDOWNES. Format: 32I1, 5F4.1, F4.2, 3F4.1, 8F4.0, 5I2.

2. Number of frequency lines and corresponding heights of F-trace in km NUMF, (ITRCF(I,2), I = MINFF, IFOM). Format: 33I4.

3. Number of frequency lines and corresponding amplitudes of F-trace NUMF, (IHHO(I), I = MINFF, IFOM). Format: 33I4.

4. Number of frequency lines and corresponding heights of E-trace in km NUME, (ITRCF(I,3), I = MINFE, IFOE). Format: 33I4.

5. Number of frequency lines and corresponding amplitudes of E-trace NUME, (IHHX(I), I = MINFE, IFOE). Format: 33I4.

6. Number of elements in array DOP for F-trace KFF. Format: 33I4.

7. Doppler transition velocities, frequencies and Doppler number changes for F-trace (DOP(I), TRAN(I), IOLD(I), NEW(I), I = 1, KFF). Format: 10 (F5.0, F4.1, 2I1).

8. Average amplitude of the trace normalized at 100 km for F-trace KFF, (DOP(I), I = 1, KFF). Format: I2, 18F5.1.

Records 6, 7, 8 are repeated with the same format for E and Es-traces. Tape 4 contains only one record for each ionogram, which consists of 32 preface characters and list of parameters (MPREF(I), I = 1, 32), FMINF, FOF1, FOF2, FXI, FMUF, FM3000, FMINE, FOES, HOM, YMM, HPRMF, HPRMF2, HPRME, HPRMES, SPREDF, SPREDE, ISFF, ISEF, JDOWNF, JDOWNE, JDOWNES. Format: 32I1, 5F4.1, F4.2, 3F4.1, 8F4.0, 5I2.

5.0 MATHEMATICAL OR LOGICAL PROCEDURES

5.1 Subroutine FNDFOF2

The hyperbolic function used to fit the X-trace near its critical frequency is

$$h_x = h_0 + \frac{1}{a+bf}, \; h_0,\, a,\, b = \text{coefficients} \tag{5.1}$$

and the function to describe the corresponding O-trace is

$$h_o = h_0 + \frac{1}{a+bf^*}; \; f^* = f + \frac{1}{2}\, fH. \tag{5.2}$$

Three points are used to construct the hyperbola which is determined in such a way that the distances are x, -x and x; where x is a positive or negative number. The range deviations of the three points $(f_i,\, h_i)$ from the curve are

$$h_i - \left(h_0 + \frac{1}{a+bf_i}\right) = (-1)^{i-1}x; \; i = 1,\, 2,\, 3. \tag{5.3}$$

These equations can be written in the form

$$(h_1-h_0-x)a + (h_1-h_0-x)\, f_1\, b - 1 = 0 \tag{5.4a}$$

$$(h_2-h_0+x)a + (h_2-h_0+x)\, f_2\, b - 1 = 0 \tag{5.4b}$$

$$(h_3-h_0-x)a + (h_3-h_0-x)\, f_3\, b - 1 = 0. \tag{5.4c}$$

From (5.4a) and (5.4b) one obtains

$$a = \frac{1}{h_1-h_0-x} - \frac{f_1}{f_2-f_1}\left(\frac{1}{h_1-h_0-x} - \frac{1}{h_2-h_0+x}\right) \tag{5.5a}$$

$$b = -\frac{1}{f_2-f_1}\left(\frac{1}{h_1-h_0-x} - \frac{1}{h_2-h_0+x}\right). \tag{5.5b}$$

Elimination of a and b leads to a quadratic equation for the determination of x (F. Scheid, "Numerical Analysis," Schaum's Outline Series, McGraw-Hill, p. 289, 1968):

$$\begin{vmatrix} h_1 - h_0 - x & (h_1 - h_0 - x)\, f_1 & 1 \\ h_2 - h_0 + x & (h_2 - h_0 + x)\, f_2 & 1 \\ h_3 - h_0 - x & (h_3 - h_0 - x)\, f_3 & 1 \end{vmatrix} = 0 \tag{5.6}$$

or:

$$Ax^2 + Bx + C = 0. \tag{5.7}$$

The coefficients A, B and C are:

$$A = 2\,(f_1 - f_3) \tag{5.8a}$$

$$B = B_0 + Ah_0 \tag{5.8b}$$

$$C = C_0 - C_1\, h_0 \tag{5.8c}$$

where

$$B_0 = -\, f_1(h_3+2h_1-h_2) - f_2(h_3-h_1) - f_3(h_2-2h_3-h_1) \tag{5.8d}$$

$$C_0 = f_1h_1(h_3-h_2) + f_2h_2(h_1-h_3) + f_3h_3(h_2-h_1) \tag{5.8e}$$

$$C_1 = f_1(h_3-h_2) + f_2(h_1-h_3) + f_3(h_2-h_1). \tag{5.8f}$$

Selecting the smaller of the two solutions for equation (5.7) we get:

$$x = -\frac{B}{2A}\left[1 - \sqrt{1 - \frac{4AC}{B^2}}\right] \tag{5.9}$$

$|x|$ will be minimum if $4AC/B^2 = 0$. This may not be possible to achieve, but one can find the minimum value of $|AC/B^2|$ by setting

$$\frac{d}{dh_0}\left(\frac{AC}{B^2}\right) = 0 \tag{5.10}$$

resulting in

$$h_0 = \frac{C_1\; B_0 + 2\; AC_0}{AC_1}. \tag{5.11}$$

At this point, the X-hyperbola is specified and so is the corresponding O-hyperbola.

Next we are going to discuss how the three points are selected. Suppose there are N points on the baseline after the trace center, the triple-point sets to which hyperbolas are fitted are as follows

Group 1			Group 2			Group 3		
P_1	P_2	P_3	P_1	P_3	P_5	P_1	P_4	P_7
P_2	P_3	P_4	P_2	P_4	P_6	P_2	P_5	P_8
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
P_{N-2}	P_{N-1}	P_N	P_{N-4}	P_{N-2}	P_N	P_{N-6}	P_{N-3}	P_N

5.2 Subroutine SMOTH2

The function used for baseline segment fitting is

$$h = a + bf. \tag{5.12}$$

Again three points are used to construct a straight line such that the points are passed through by it and are equidistant from it. Equation (5.12) becomes

$$a + bf_1 - h_1 = x \tag{5.13}$$

$$a + bf_2 - h_2 = - x \tag{5.14}$$

$$a + bf_3 - h_3 = x. \tag{5.15}$$

By solving the equations, one obtains

$$b = \frac{h_3-h_1}{f_3-f_1} \tag{5.16}$$

$$x = \frac{1}{2} [h_2 - h_1 - b(f_2 - f_1)] \tag{5.17}$$

$$a = h_1 + x - bf_1 \tag{5.18}$$

and the straight line is defined.

If the smoothing is operating on a point P(I) proceeding in the direction of the higher frequency, five more points P(I-3), P(I-2), P(I-1), P(I+1) and P(I+2) are also used. All combinations of selecting three points for fitting are performed and the amplitudes of the six frequencies on the line are summed. The point on the line yielding the maximum sum replaces the old baseline point.

5.3 E-Region Trace Extraction

A method to extract the O-trace of the E-region has been developed. The procedure assumes the electron density profile for the E-region can be represented by a parabolic expression (see Davies,[3] p. 135)

$$N = N_m \left(1 - \left(\frac{h-h_E}{y_E}\right)\right). \tag{5.19}$$

The virtual height can be evaluated by

$$h'(f) = \int_0^{h(f)} \mu' \, dh \tag{5.20}$$

using Eq. (5.19) gives

$$h'(f) = h_E - y_E + \frac{1}{2} y_E \frac{f}{f_E} \ln \left(\frac{f_E+f}{f_E-f}\right) \tag{5.21}$$

where h_E is the height of the peak of the E-layer parabola, y_E is the semi-thickness and f_E is the critical frequency of the E-layer, foE. In the evaluation of equation (5.21) the effect of the geomagnetic field on the group index of refraction μ' is neglected. This assumption has no effect on the data, which is obtained experimentally and we comment that Eq. (5.21) is used as an analytical equation to give the

shape of the E-region trace. By varying the parameters we get many different parabolic type shapes from which we choose the one with maximum amplitude per point. Thus while the assumption of zero geomagnetic field was made in the evaluation of Eq. (5.21) we feel it has little bearing in the subsequent results.

The solution for the trace is obtained by maximizing the average signal amplitude of the ordinary vertical echoes traced out by the h'(f) function. By varying the three parameters h_E, y_E, and f_E we search all possible curves traced out and select the one with maximum amplitude. The computation involves evaluating the height of the trace at particular frequencies given the three parameters. To better understand this procedure we make the following substitutions let $R = f/f_E$, $h_{BE} = h_E - y_E$ = bottom of layer, and define $\phi = R \ \ln \left(\frac{1+R}{1-R}\right)$. Equation (5.21) becomes

$$h'(f) = h_{BE} + \frac{1}{2} y_E \phi. \tag{5.22}$$

In the actual execution of the program $h'(f)$, h_E, y_E, and hence h_{BE}, are all integers representing digitized positions in the ionogram, i.e. bin numbers. To solve equation (5.22) to trace out h'(f) curve on the ionogram we are only intersted in values of

$$\frac{1}{2} y_E \phi$$

that are integers, i.e. positions on the range grid. In particular, given values of h_E, y_E, and foE we wish to relate frequency (actually $R = f/f_p$) to virtual height via Eq. (5.22). Since the virtual heights in Eq. (5.22) are in terms of integer range bins what we wish to solve is

$$\phi = \frac{2}{y_E} * N \tag{5.23}$$

where N is $h'(f) - h_{BE}$ (an integer) for all possible values of N. In the solution, values of N between 0.5 and 1.5 are designated as bin 1, 1.5 to 2.5 as bin 2, etc. so the equation we actually solve is

$$R \ln \frac{1+R}{1-R} = (N - .4999) * \frac{2}{y_E} \tag{5.24}$$

for the range of y_E considered (1 to 8) and for a range of N (1 to 25). This includes semi-thicknesses from 5 to 40 km and covers the region of an ionogram from 60 to 260 km. By solving Eq. (5.24) we can generate a table of bins vs R. Thus when solving for the E-region trace we take f and f_E, form their ratio and immediately have $h'(f)$ from the table, h_E, and y_E. To solve Eq. (5.24) (a transcendential eq.) we re-express it in the form

$$\psi(R) = R \ln \frac{1+R}{1-R} - (N - .4999) * \frac{2}{y_E} \tag{5.25}$$

and use the Newton-Raphson method to find the solutions for $\psi(R) = 0$. For this we need $\psi'(R)$ which is

$$\frac{d\psi(R)}{dR} = \ln \frac{1+R}{1-R} + R \frac{d}{dR} \ln \frac{1+R}{1-R} \tag{5.26}$$

using the relationship $\frac{d}{dx} \ln \mu = \frac{1}{\mu} \frac{d\mu}{dx}$ we have

$$\frac{d}{dR} \ln \frac{1+R}{1-R} = \frac{1-R}{1+R} \left\{\frac{1}{1-R} + \frac{1+R}{(1-R)^2}\right\} \tag{5.27}$$

which simplifies to

$$\frac{1}{1+R} + \frac{1}{1-R} = \frac{2}{1-R^2} \tag{5.28}$$

thus

$$\frac{d\psi(R)}{dR} = \ln \frac{1+R}{1-R} + \frac{2R}{1-R^2} \tag{5.29}$$

Newton-Raphson gives for the n+1 guess of R

$$R_{n+1} = R_n - \frac{\psi(R)}{\psi'(R)}. \qquad (5.30)$$

For an initial guess we consider

$$\phi = R \, \ell n \, \frac{1+R}{1-R}. \qquad (5.31)$$

Forgetting the linear R term we can write

$$e^{\phi} = \frac{1+R}{1-R} \rightarrow e^{\phi} - e^{\phi}R = 1 + R \qquad (5.31)$$

$$R(1 + e^{\phi}) = e^{\phi} - 1$$

or

$$R_{\substack{\text{Initial}\\ \text{Guess}}} = \frac{e^{\phi}-1}{e^{\phi}+1} \text{ and } \phi \text{ is given by Eq. (5.23).}$$

The table of numbers appears in subroutine PARBOL, we evaluate the ratio f/f_E and find the position in the table that is greater than the ratio. That position is equal to the number of range bins, i.e. $h(f) - h_{BE}$.

5.4 Error Routines and Indications

IERR is the error flag used all through the program. It will be set when the following cases occur and the output parameters are assigned equal to 99.9 or 999. for indication.

Error Condition Checks	Internal and External Indications	Recovery Procedures or Action Required
1. Subroutine TCENTER - if no data found in the ionogram	Internal-IERR = 1 External-foF2 = 99.9 HMIN = 999. FMIN = 99.9 SPREDF = 999. ISFF = 99 ISEF = 99	Output parameter values to tape 4 only to signify that ionogram cannot be processed. Then continue to the next ionogram.
2. Subroutine BASE-(i) if fewer than 3 poles found in the center window (ii) if fewer than 5 points on the baseline.	"	"
3. Subroutine FNDFOF2- if last frequency of baseline is lower than the trace center.	"	"

4. When the program determines there is no E-region trace, foE for that ionogram is set equal to zero.

6.0 PROGRAM RESTRICTIONS AND TIMING

6.1 Restrictions

1. The program processes only the vertical ionograms of Digisonde 256 or 128PS data.

2. The maximum number of frequency of an ionogram is 160. If more frequencies are preferred, the dimension of arrays IA, ITRCF, IHHO, IHHX, IHHOM, IHHXM, IBSUM, and the variable MAXF have to be changed to the desired values.

3. The program requires 130K (octal) of central memory to run.

4. The average run time for one ionogram (14 records) is <2 CPU second.

7.0 REFERENCES

1. Reinisch, B. W. and Huang Xueqin, "Automatic Calculation of Electron Density Profiles from Digital Ionograms. 3. Processing of Bottomside Ionograms" (to be published in Radio Science, 1983).

2. Reinisch, B. W., J. S. Tang and R. R. Gamache, "Automatic Scaling of Digisonde Ionograms Test and Evaluation Report," Scientific Report No. 4, AFGL-TR-82-0324, ULRF-421/CAR, September 1982.

3. Davies, K., Ionospheric Radio Propagation, NBS Monograph 80, 1965.

4. Scneid, F., Numerical Analysis, Schaum's Outline Series, McGraw-Hill, 1968.

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